REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
24 January 2005	Technical Report	1 January 2004 - 30 September 2004

4. TITLE AND SUBTITLE
High Frequency Acoustics and Signal Processing for Weapons

5a. CONTRACT NUMBER

5b. GRANT NUMBER
N00014-04-1-0198

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
David L. Bradley, R. Lee Culver

5d. PROJECT NUMBER
ARL #12152

5e. TASK NUMBER
ARL #01

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Applied Research Laboratory, Penn State University, P. O. Box 30, State College, PA 16804-0030

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Dr. John A. Tague, Office of Naval Research, Ballston Tower 1, 800 North Quincy Street, Arlington, VA 22217-5660

10. SPONSOR/MONITOR'S ACRONYM(S)
ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A
Approved for Public Release
Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Determine for a broad range of frequencies (nominally 10-100 kHz) the limitations imposed by the oceanic envionrment on the exploitation of coherent signal structure. This understanding is required in order to optimize sonar signal processing structures (e.g. channel conditioning, especially in shallow water), for wideband signal and processor design, and for acoustic propagation modeling.

15. SUBJECT TERMS
coherent signal structure, sonar signal processing, acoustic propagation modeling

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			David L. Bradley
Unclassified	Unclassified	Unclassified	UU	8	**19b. TELEPHONE NUMBER** *(Include area code)* (814) 863-9916

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

High Frequency Acoustics and Signal Processing for Weapons

David L. Bradley and R. Lee Culver
The Pennsylvania State University, Applied Research Laboratory
P. O. Box 30, State College, PA 16804-0030
Phone: (814) 863-9916 Fax: (814) 863-8783
email: Bradley: dlb25@psu.edu Culver: rlc@enterprise.arl.psu.edu
Grant #N00014-04-1-0198
http://www.onr.navy.mil/sci_tech/ocean/onrpgahh.htm

LONG-TERM GOALS

The long-term goal of this task is to determine, for a broad range of frequencies (nominally 10-100 kHz), the limitations imposed by the oceanic environment on the exploitation of coherent signal structure. This understanding is required in order to optimize sonar signal processing structures (e.g. channel conditioning, especially in shallow water), for wideband signal and processor design, and for acoustic propagation modeling.

OBJECTIVES

Since coherent signal processing relies on the signal remaining so, while the interference does not, the experimental and theoretical objectives focus on signal coherence as a function of (elapsed) time and frequency (separation and/or bandwidth), and in particular, the impact of the medium and the development of a predictive capability. The scientific objectives of this task are to:

1. Directly measure the time and frequency correlation of individual paths in an acoustic ocean channel while varying the signal bandwidth and center frequency, as well as the source-receiver geometry, and characterizing the ocean boundaries and volume.
2. Investigate the physical mechanisms that impact the coherence of signals propagating through an ocean channel.
3. Develop a predictive model for acoustic coherence
4. Finally, apply environmental acoustic models and information to signal processing architectures in order to exploit knowledge of oceanic time and frequency correlation.

APPROACH

Our approach to directly measuring temporal and frequency correlation utilizes both pure tone (PT) and broadband signals. Concurrently, the environment is sampled using these instruments:

- ASD Sensortechnik towed CTD string
- Reson 8101 240 kHz multibeam sonar
- RDI 300kHz ADCP
- AXYS Technologies directional wave rider buoy

Frequency correlation is estimated by analyzing how correlator output (received vs transmitted signal) varies with center frequency and bandwidth. Temporal correlation is estimated by analyzing how correlator output varies with center frequency and signal length.

It is important to note that we are investigating 10's of kHz center frequencies, bandwidths up to 22kHz, and signal lengths to 1 sec, all of are significantly different from those used by most other researchers. There are few published measurements of temporal or frequency coherence for high frequencies [1-5]. We find that signal coherence remains high (>50%) for larger bandwidths and longer times than intuition had led us to expect [6].

WORK COMPLETED

Our focus to date has been high frequency ocean acoustics and the fundamental limitations to coherent signal processing. In 2002 we conducted a field experiment off the coast of Southern California, and during the last two years we have analyzed these data from the standpoint of how the acoustics impact signal processing.

During July 2002, using the research platform FLIP, a string of acoustic projectors was suspended from a surface buoy, and a string of hydrophones attached a subsurface buoy about 1km away. A problem with the fiber optic link to the hydrophones prevented data recording. However, the following month we re-deployed the hydrophone string from a ship in a 3-pt moor and were able to acquire an excellent set of acoustic data that effectively interrogated the upper 150m of the water column, including the ocean surface. The geometry is shown in Figure 1. Acoustic measurements were made twice daily using 20kHz and 40kHz center frequencies, 0.14ms and 1ms PT signals, and 8ms FM signals with 1, 7, 13 and 22kHz bandwidths. Environmental conditions were relatively calm, with wind speed averaging 7kts and rms wave height below 0.1m (the latter due to screening by nearby San Clemente Island).

In addition to recording normal environmental parameters (e.g. wind speed and CTD drops), we towed a string of CTD sensors [7] laterally through the upper 150m of the ocean in order to measure variability in the index of refraction using a very fine scale (Figure 2). In the upper 20m, Langmuir circulation apparently has pulled warmer, surface water down to depths where the surrounding temperature and sound speed are much lower. Sound speed anomalies at 20m to 50m depth are likely caused by internal waves. The acoustic paths shown in Figure 2 make it clear that different paths will be subjected to different types and levels of medium variability.

PhD student Steven Lutz has analyzed environmental and signal variation and compared it to theories by Uscinsky [8] and Flatté et. al. [9]. He has found that variability in short acoustic records is far less than that predicted by theory, essentially because the theory assumes an observation time that is long enough to observe all the variability present in the medium [10, 11]. Over the next year, Lutz will quantify how the theory should be applied to signal processing for underwater acoustic systems.

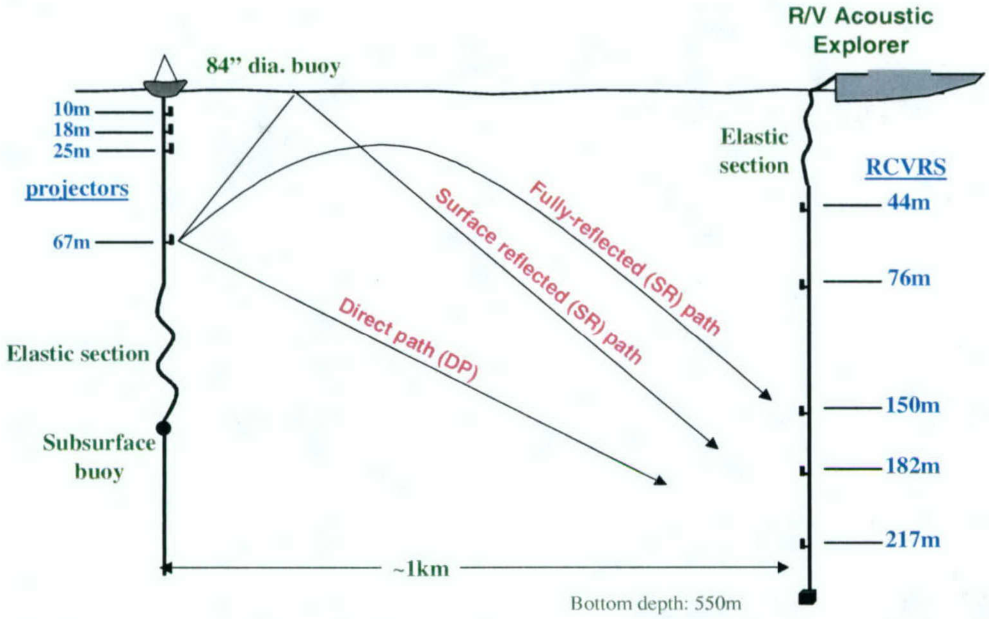

Figure 1: August 2002 measurement geometry. The receive array was suspended from R/V Acoustic Explorer, which was in a three-point moor, using an elastic member. Acoustic projectors were mounted on the riser of an elastically moored surface buoy and controlled via RF link R/V Acoustic Explorer.

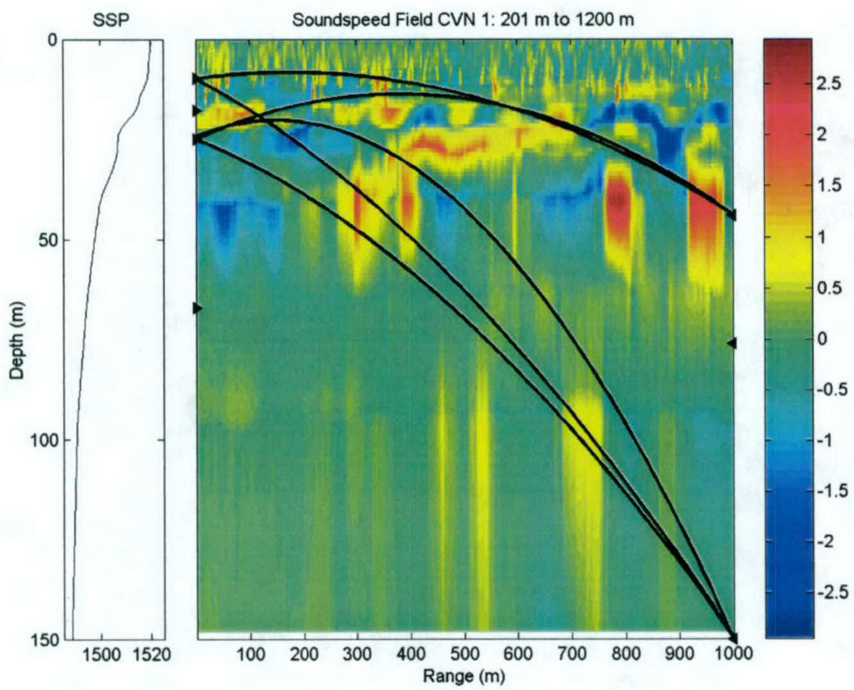

Figure 2: August 2002 measurements of mean sound speed (left) and sound speed anomaly (right) with selected rays superimposed. Fine scale variation near the surface is due to Langmuir circulation. Larger scale variation at 25 to 60 m depth is due to internal waves.

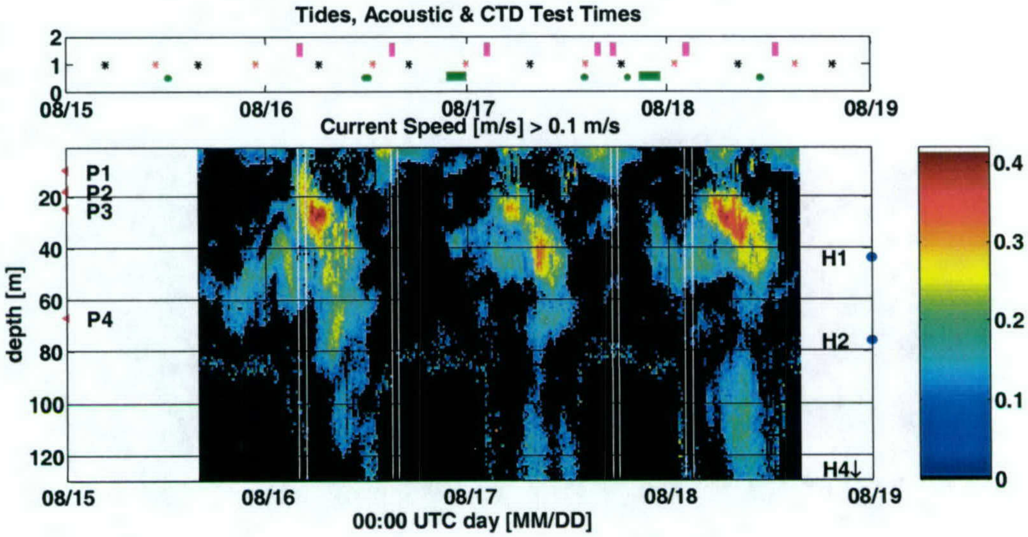

Figure 3: Current measurements made during August 2002 at the experiment site. A high speed current jet (marked in red) was observed daily between 15 and 45 m depth corresponding to the transition from high-high tide to low-low tide.

Separately, MS student Rachel Romond analyzed August 2002 current measurements (Figure 3) and found a "current jet" that occurred daily at 20m to 60m depth as the tide transitioned from highest high to lowest low [12]. The current data show daily periodic variation in which times of high current activity coincide with daily transition from high tide to low tide. During active times (the data in red in Figure 3), the mean current speed between 15 m and 45 m depth peaked at about 0.35 m/s. During quiescent times, the mean current speed at these depths was .05 and 0.6 m/s, and during the time of intermediate activity, the mean speed was .10 m/s.

Studying the acoustic data, Romond found that acoustic variability was strongly correlated with the speed of the jet (see Figure 4). In fact, the scintillation indices corresponding to paths that passed through the 20m to 60m depth strata increased five fold when the high speed jet was present. Also, scintillation indices corresponding to paths that did not pass through the 20m to 60m strata did not change, whether or not the jet was present. Romond was able to explain this variability in terms of wave propagation in random media (WPRM) theory and quantify the impact on signal processing [13].

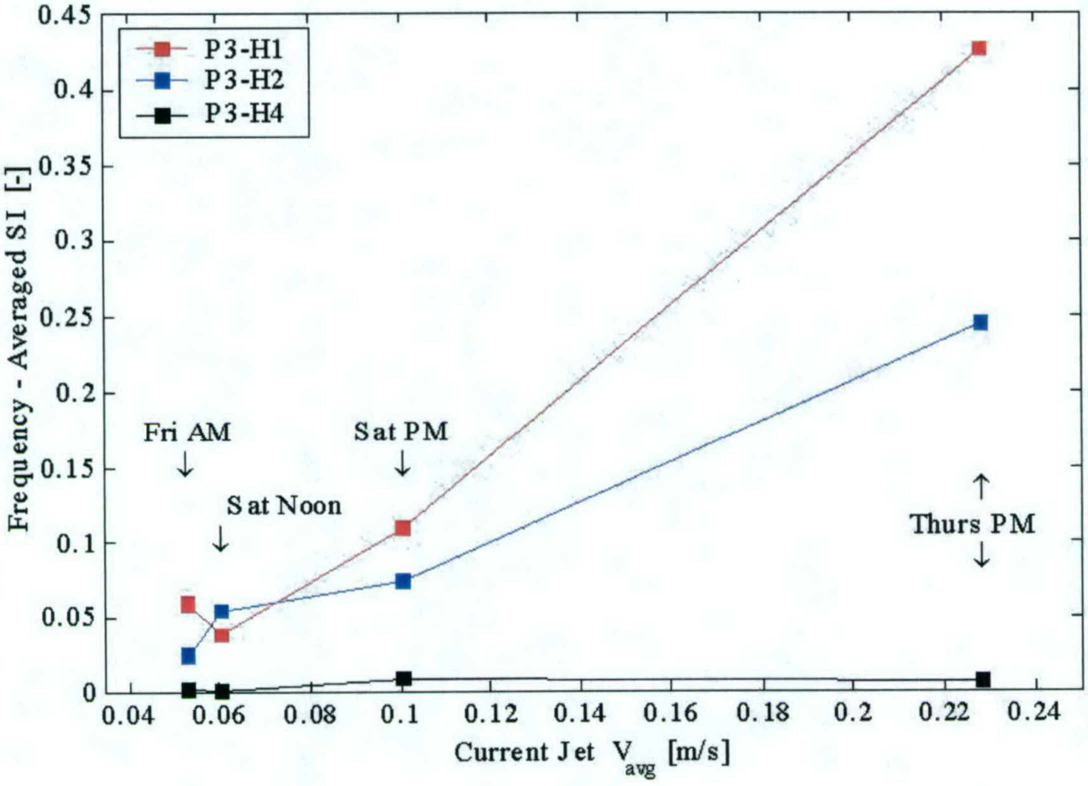

Figure 4: Correlation between measured scintillation index andh speed of the current jet shown.

RESULTS

The August 2002 acoustic data offered an excellent opportunity to study the decorrelation of high frequency acoustic signal forward scattered by the ocean surface. The bandwidth dependence of correlation loss for surface reflected signals is an important issue whenever the surface reflected path is an important component of acoustic propagation between the source and receiver or target [5]. This is true for acoustic communications, mine detection and classification, and torpedo detection, classification and localization (DCL). The surface reflected path will be important when the source, receiver, and/or target is near the ocean surface, where surface warming often leads to shadow zones and no direct path propagation. This path is also important in quasi-isovelocity conditions where the direct path and surface reflected signals are approximately the same strength and thus interfere. Under such conditions, the frequency correlation theory predicts how much bandwidth is available for coherent processing as a function of sea state.

In 1974, Reeves showed that increasing signal bandwidth from 100Hz to 2kHz caused the surface reflected signal to become less correlated with the transmitted signal [1]. Strangely, this phenomenon attracted little attention until recently, under the ARL project, when it was investigated for up to 13kHz bandwidth by Keranen [6] and extended to 22kHz bandwidth in the August 2002 experiment. From these data, we have developed theory that predicts the how the correlation drop depends upon sea state and signal bandwidth [14, 15]. As shown in Figure 5, the frequency correlation prediction using linear systems theory matches the measurements quite well.

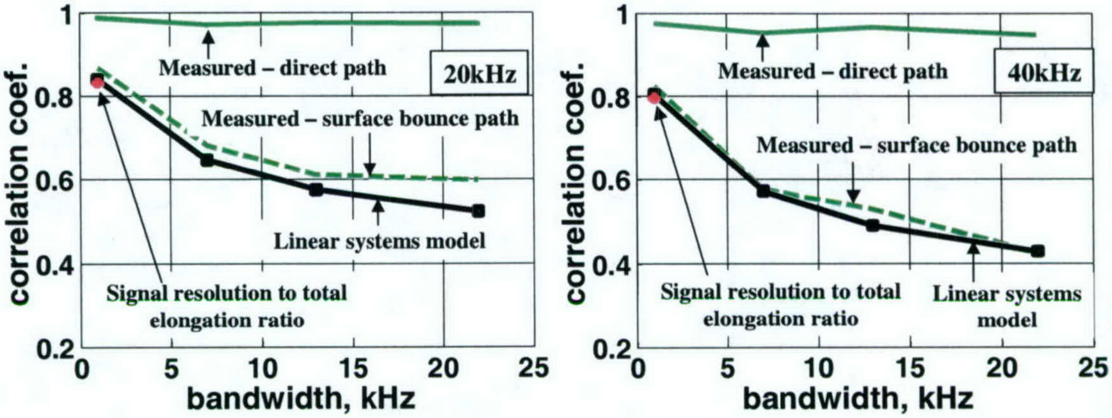

Figure 5: Measured and modeled frequency correlation for the 67m deep projector and received at the 217m deep hydrophone (left: 20kHz; right: 40kHz). Measured for direct path (green solid) and surface bounce path (green dashed); modeled using linear systems theory (black) and signal resolution to total temporal elongation ratio theory (red) [14, 15]

IMPACT/APPLICATIONS

The motivation for investigating acoustic coherence in the ocean channel is a desire to improve the performance of undersea weapon systems that utilize acoustics to detect, classify and localize the target. Our emphasis is on temporal coherence and broadband signals because the undersea weapons development community is increasing signal time-bandwidth product at traditional weapons frequencies. Advanced, coherent signal processing architectures are contemplated, whose effectiveness will depend upon the impact of the ocean environment on temporal and frequency coherence.

TRANSTIONS

None.

RELATED PROGRAMS

Programs that are both closely related and this project maintains direct and constant interaction with our Ocean Acoustics, Undersea Signal Processing and Sensors, Sources and Arrays.

REFERENCES

[1] Reeves, J.C. *Distortion of Acoustic Pulsed Reflected from the Sea Surface,* Ph.D. Dissertation, University of California, Los Angeles (1974).

[2] Adams, S.L. and J.W. Doubek, *Frequency coherence and time coherence in random multipath channels,* J. Acoust. Soc. Am. **62**, 286-294 (1977).

[3] Brill, M.H., X. Zabal, and S.L. Adams, *Time spread of acoustic signals reflecting from a fixed rough boundary,* J. Acoust. Soc. Am. **75**, 1062-1070 (1984).

[4] Rolt, K.D. and P.A. Abbot, *Littoral coherence limitations on acoustic arrays,* in Acoustical Imaging, Vol. 23, edited by Lees and Ferrari (Plenum Press, New York, 1977).

[5] Dahl, P.H., *High-Frequency Forward Scattering from the Sea Surface: The Characteristic Scales of Time and Angle Spreading,* IEEE J. Oceanic Eng. **26**, 141-151 (2001).

[6] Keranen, J.G., *Effect of the ocean Environment on the Coherence of Broadband Signals,* M.S. Dissertation, The Pennsylvania State University, State College (2001).

[7] Sellschopp, J., "A towed CTD chain for two-dimensional high resolution hydrography," Deep-Sea Research I, Vol. 44, No. 1, pp. 147-165 (1997).

[8] Uscinski, B.J., "The Elements of Wave Propagation in Random Media," (McGraw-Hill, New York, 1977).

[9] Flatté, S.M., R. Dashen, W.H. Munk, K.M. Watson, and F. Zachariasen, "Sound Transmission through a Fluctuating Ocean," (Cambridge University Press, Cambridge, 1979).

[10] Lutz, S.D., R.L. Culver, and D.L. Bradley, "Amplitude and time fluctuations and their relationship to temperature variations," J. Acoust. Soc. Am., Vol. 113, No. 4, Pt. 2, April 2003.

[11] Lutz, S.D., D.L. Bradley, and R.L. Culver, "High Frequency Intensity Fluctuations," Proceedings of the Seventh European Conference on Underwater Acoustics, ECUA 2004, Delft, The Netherlands, July 2004.

[12] Romond, R.A., "Effects of the Propagation Environment on Coherence of Underwater Broadband Acoustic Signals," MS thesis in Acoustics, Penn State University, December 2003.

[13] Romond, R.A., R.L. Culver, and D.L. Bradley, "Observations of the effect of an ocean current jet on high frequency acoustic propagation," (in preparation – will be submitted to JASA).

[14] Culver, R.L. and D.L. Bradley, *On the relationship between signal bandwidth and coherence for ocean surface forward scattered signals,* ONR High Frequency Ocean Acoustics Conference, San Diego, CA, March 2004.

[15] Culver, R.L. and D.L. Bradley, "On the relationship between signal bandwidth and frequency correlation for ocean surface forward scattered signals," (submitted to JASA, 2004).

PUBLICATIONS

Culver, R.L. and D.L. Bradley, *On the relationship between signal bandwidth and frequency correlation for surface forward scattered signals*, ONR High Frequency Ocean Acoustics Conference, San Diego, CA, March 2004.

Culver, R.L. and D.L. Bradley, *Surface ship wake remote sensing using an AUV-mounted multibeam sonar*, J. Acoust. Soc. Am., Vol. 115, No. 5, Pt. 2, May 2004.

Culver, R.L. and D.L. Bradley, *On the relationship between signal bandwidth and frequency correlation for ocean surface forward scattered signals*, (submitted to JASA, 2004).

Lutz, S.D., D.L. Bradley, and R.L. Culver, *High frequency intensity fluctuations: Comparison of theory with experiment*, J. Acoust. Soc. Am., Vol. 114, No. 4, Pt. 2, October 2003.

Lutz, S.D., D.L. Bradley, and R.L. Culver, *A modified approach to scintillation index analysis of intensity*, J. Acoust. Soc. Am., Vol. 115, No. 5, Pt. 2, May 2004.

Lutz, S.D., D.L. Bradley, and R.L. Culver, *High Frequency Intensity Fluctuations*, Proceedings of the Seventh European Conference on Underwater Acoustics, ECUA 2004, Delft, The Netherlands, July 2004.

Romond, R.A.R.L. Culver, and D.L. Bradley, *Effects of the Propagation Environment on Coherence of Underwater Broadband Acoustic Signals*, J. Acoust. Soc. Am., Vol. 114, No. 4, Pt. 2, October 2003.

Romond, R.A., *Effects of the Propagation Environment on Coherence of Underwater Broadband Acoustic Signals*, MS thesis in Acoustics, Penn State University, December 2003.

Romond, R.A., R.L. Culver, and D.L. Bradley, *Observations of the effect of an ocean current jet on high frequency acoustic propagation*, (in preparation – will be submitted to JASA).

PATENTS

None

HONORS/AWARDS/PRIZES

None.